COMPUTER MODELING OF MAGNET FOR SC200 SUPERCONDUCTING CYCLOTRON

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Abstract

The superconducting cyclotron SC200 for proton therapy is designing by ASIPP (Hefei, China) and JINR (Dubna, Russia) will be able to accelerate protons to the energy 200 MeV with the maximum beam current of 1 μA. By computer simulation with 3D codes the cyclotron magnet principal parameters were estimated (pole radius 0.62 m, outer diameter 2.2 m, valley depth 0.3 m, height 1.22 m, weight ~30 t). The required isochronous magnetic field is shaped with accuracy some mT. Four fold symmetry and spiralized sectors with minimal gap 5 mm at extraction provide the stable beam acceleration till 10 mm from the pole edge.

CYCLOTRON OVERVIEW AND IT'S PARAMETERS

In order to respond to the increasing interest in Russia and China for proton therapy, JINR and ASIPP have started the development of a dedicated proton therapy facility in frame of the China-Russia joint research center on superconducting protons accelerator. The center has been founded in Hefei, east China's Anhui province recently. The research center, co-built by the Joint Institute for Nuclear Research of Russia and Institute of Plasma Physics of Chinese Academy of Sciences, aims at developing SC200 - China's first compact superconducting cyclotron for medical application - within three years. SC200 will be used for accurate treatment of cancer. The systems and components related to SC200 is expected to be manufactured by the Institute of Plasma Physics by 2017 and both parties will jointly assemble these systems and components and complete the whole project by 2018.

The main SC200 cyclotron design characteristics:

- Compact design similar to the lot existing cyclotrons
- Fixed energy, fixed field and fixed RF frequency
- Bending limit W=200 MeV
- Accelerated particles: protons
- Superconducting coils enclosed in cryostat, all other parts are warm
- Injection by PIG ion source
- Extraction with an electrostatic deflector

EXPECTED SC200 MAGNET CHARACTERISTICS AND DESIGN GOAL

The simulation and design of the SC200 magnetic system was based on it's main characteristics:

- Four-fold symmetry and spiral sectors
- Deep-valley concept with RF cavities placed in the valleys
- Small sectors gap near beam extraction
  - Accelerate ~10 mm from pole edge ⇒ facilitate extraction
- Pole radius = 62 cm
- Outer diameter = 220 cm
- Valley depth = 30 cm
- Height = 120 cm
- Hill field = 4.5 Tesla, valley field = 2.8 Tesla
- Weight about 30-35 tons

During the magnet simulation the design goals were solved:

- Optimization of the magnet sizes
- Realizing of the vertical focusing (Q_z) at the extraction region as closed as possible to 0.5 (to decrease the vertical beam size and minimize the median plane effects)
- Keep last orbit as closed as possible to pole edge
- Minimize iron weight, keeping the stray field at an acceptable level
- Avoid resonances

MAGNET SYSTEM SIMULATION

The preliminary choice of the magnet system parameters was provided by 2D codes (POISSON [1] and OPERA-2D [2]). At this stage the basic magnet system sizes and sectors gap parameters were estimated. The optimization of the spiral sectors parameters and final choice for magnet design has been made by TOSCA, the magneto-static module of OPERA-3D and 3D code ANSOFT MAXWELL [3].

At the each step of magnet optimization the simulated magnetic field maps were analyzed by the beam dynamic codes and the beam extraction procedure was studying too.

The SC200 cyclotron model view is in Fig.1.

The average magnetic field shaping was realized by:

- Magnet pole profiling (additional valleys sectors are used),
- Sectors gap profiling at the final radii,

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- Small profiling of the sectors azimuth width,
- Tuning of the vertical and radial position of the magnet main excitation coils.

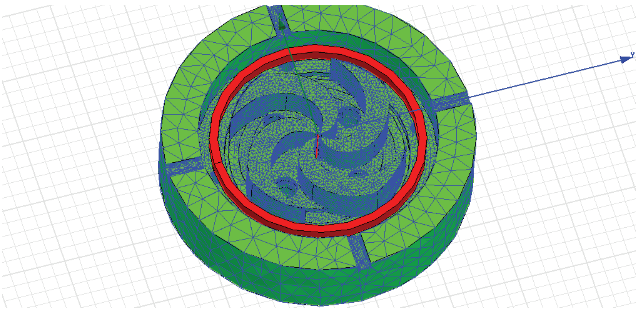

Figure 1: Layout of the MAXWELL model for SC200 cyclotron.

The shaped average magnetic field is shown in Fig.2. The final deviation of the average magnetic field from isochronous one was achieved in range ±(5-6) mT (Fig.3).

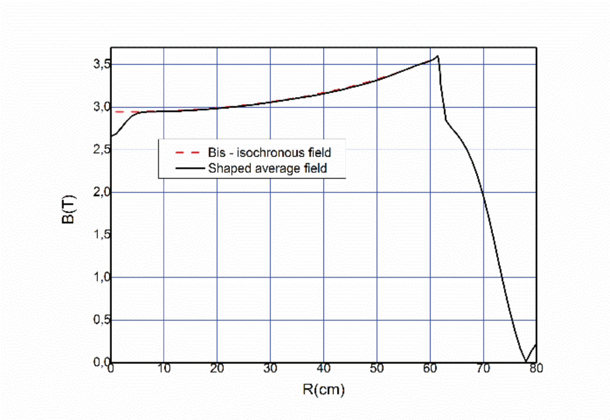

Figure 2: Average magnetic field.

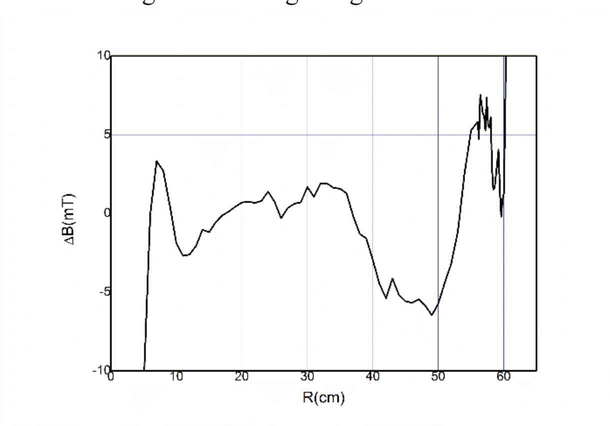

Figure 3: Accuracy of the required magnetic field shaping.

The basic number Fourier harmonics are shown in Fig.4 and the fourth harmonic phase derivative – in Fig.5.

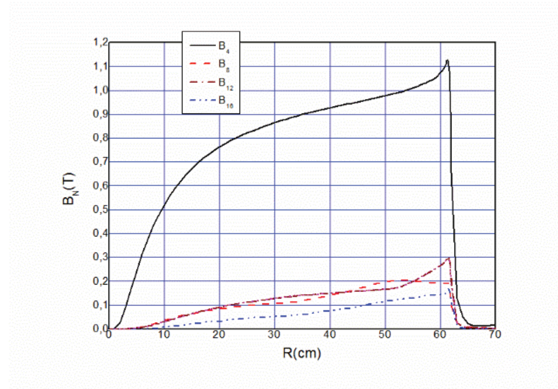

Figure 4: N-number Fourier harmonics of cyclotron magnetic field.

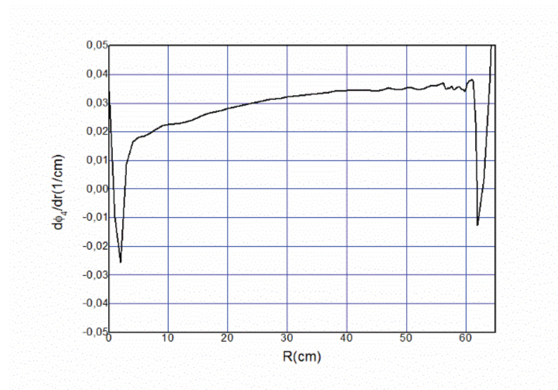

Figure 5: Derivative of the fourth harmonic phase.

The optimized sectors geometry provides vertical focusing Q_z~ 0.3, near the cyclotron extraction region Q_z was shaped as close as possible to 0.35 (Fig.6). Such law of Q_z leads to smaller vertical beam size and not so hard tolerance condition for the magnetic field horizontal components in the median plane of the cyclotron. The azimuth magnetic field distribution for three cyclotron radii R=20, 40 and 60 cm is shown in Fig.7.

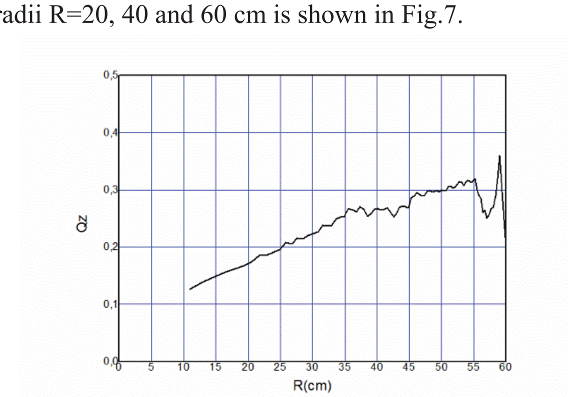

Figure 6: Vertical betatron frequency for the isochronous cyclotron magnetic field.

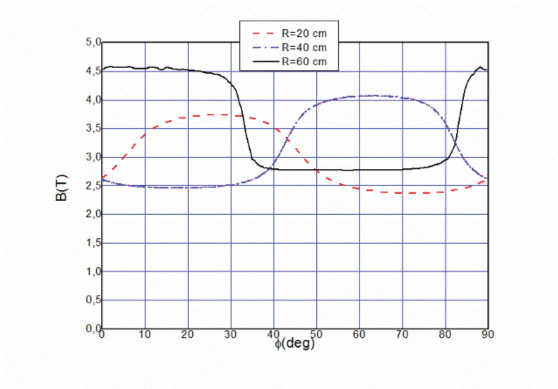

Figure 7: SC200 magnetic field for R=20, 40, 60 cm.

Main parameters of magnet are shown in Table 1.

Table 1: Main Parameters of the Magnet SC200

Parameters	**Value**
Average field (central/extraction)	2.9/3.6 T
Hill/valley field	2.8/4.6 T
Number of sectors	4
Sector angle	40 deg
Sector gap (max/min)	40/5 mm
Valley gap (max/min)	600/530 mm
Pole diameter	1.24 m
Dimension (diameter/height)	2.2/1.22 m
Ampere*turns (1 coil)	750 000
Weight	30 t

The magnetic field simulation has resulted in providing the preliminary cyclotron design (Fig.8).

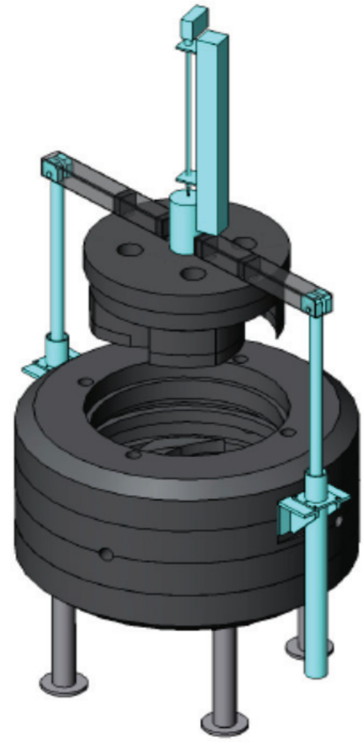

Figure 8: SC200 cyclotron magnet preliminary design.

CONCLUSION

The computer modelling by the 3D codes of the magnet system for SC200 superconducting cyclotron has been performed. The fine optimization of the magnet yoke and spiral sectors parameters has been realized in the cyclotron compact design. The computer models have provided the field maps which allowed to verify by beam dynamic simulation the feasibility of a superconducting proton cyclotron with energy 200 MeV. The technical design of the cyclotron should be realized to the end of 2016.

REFERENCES

[1] POISSON/SUPERFISH User's Guide, LA-UR-87-115, Los Alamos Accelerator Code Group.
[2] OPERA 2D and 3D, Software for Electromagnetic Design, www.cobham.com/technicalservices
[3] MAXWELL 3D, www.ansoft- corporation.software

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